Multi-spectral Solar Cells

Shouyuan Shi, James Mutitu, and Dennis W. Prather

UNIVERSITY OF DELAWARE

Background

- We currently work on the design, fabrication, and manufacture of a wide array of photonic devices including: photonic crystals, silicon lasers, high speed modulators and solar cells.
- We have several active projects in silicon photonics: lasers, routers, modulators, MEMS, mirco-fluidics, OPSIS (foundry based), etc.
- We have worked on light trapping in thin-film silicon solar cells in the DARPA Very High Efficiency Solar Cell (VHESC) program.
- We have a strong and ongoing collaboration with the Institute of Energy Conversion (IEC) at the University of Delaware, where we apply photonic engineering device concepts to thin-film solar cells (CIGS).

Our Vision

- To reach the "next level" of solar cell engineering, a holistic approach to design, integration, and manufacturing where materials, devices, and photonic engineering are monolithic.

- Application of photonic engineering device concepts to photovoltaics is non-trivial, it needs a multi-disciplinary approach where groups of various backgrounds work seamlessly together.

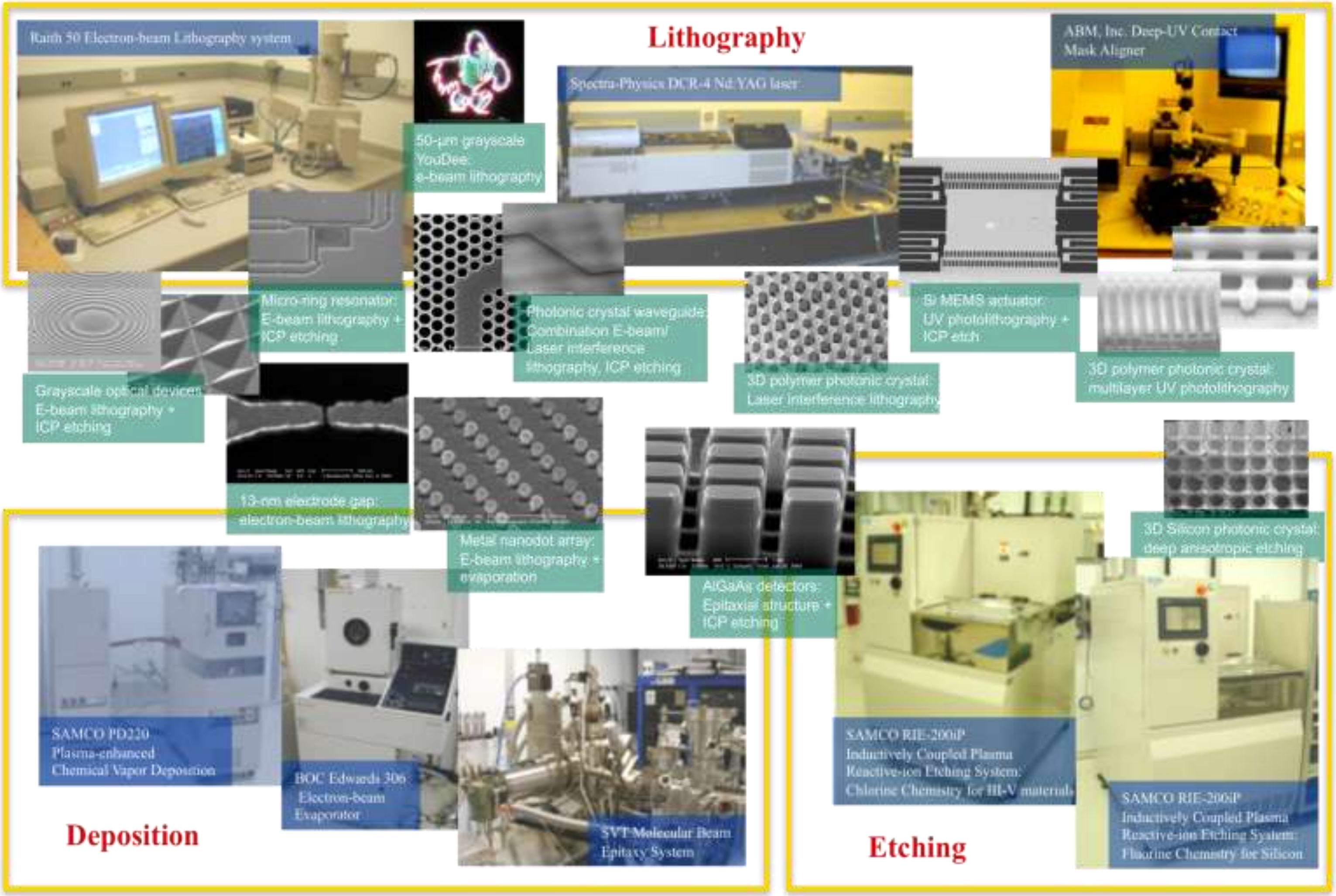
- For this to happen, a new paradigm is needed where the emphasis is on synergy and finding ways that different technologies can be mutually beneficial.

- A good example of this is the semiconductor manufacturing industry, where all components are built to work together from the on-set to build > 60% efficient solar cells, under very high concentration 10,000X.

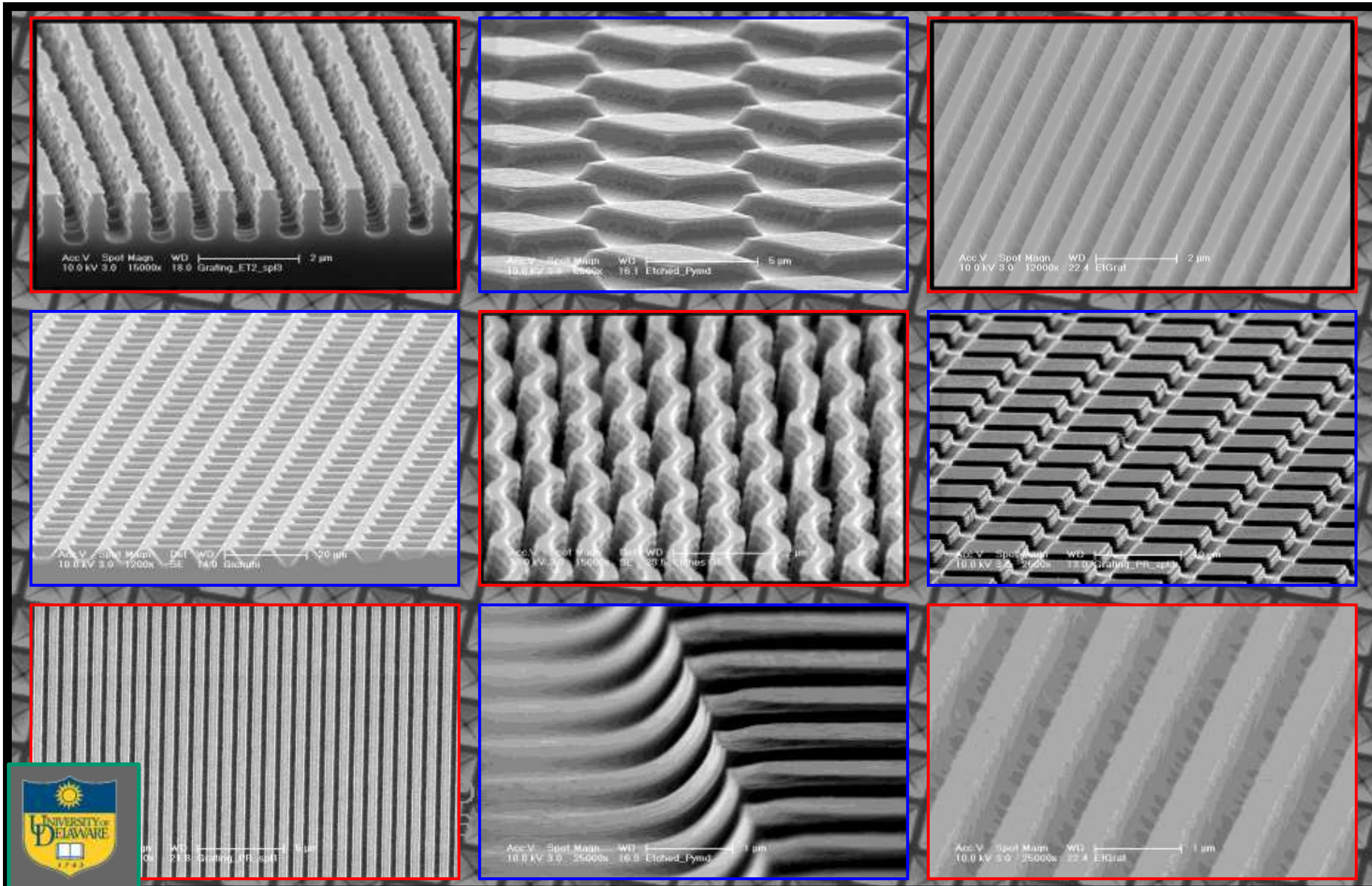
Nano-Fabrication Facility

EQUIPMENT:

- UV, DUV, AND EBEAM LITHOGRAHY
- ICP ETCHING WITH FL AND CL GASES
- PECVD, MOCVD, MBE
- EBEAM EVAPORATION
- CHIP PACKAGING
- FLIP-CHIP BONDING
- DIFFUSION FURNACES
- RF TESTING AND INTEGRATION



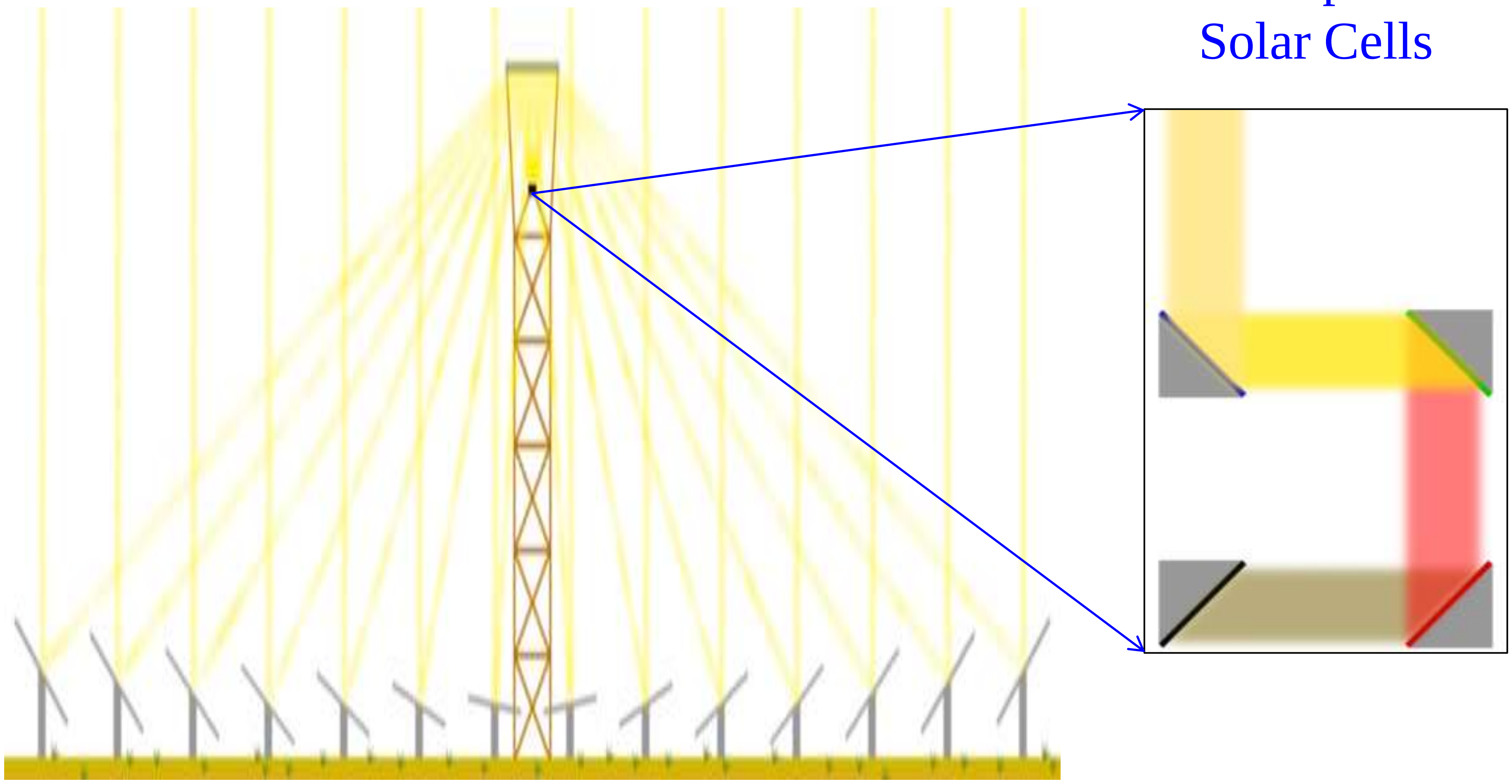
Fabrication of Micro and Nano Structures



Solar Tower and Light Spectrum Splitter

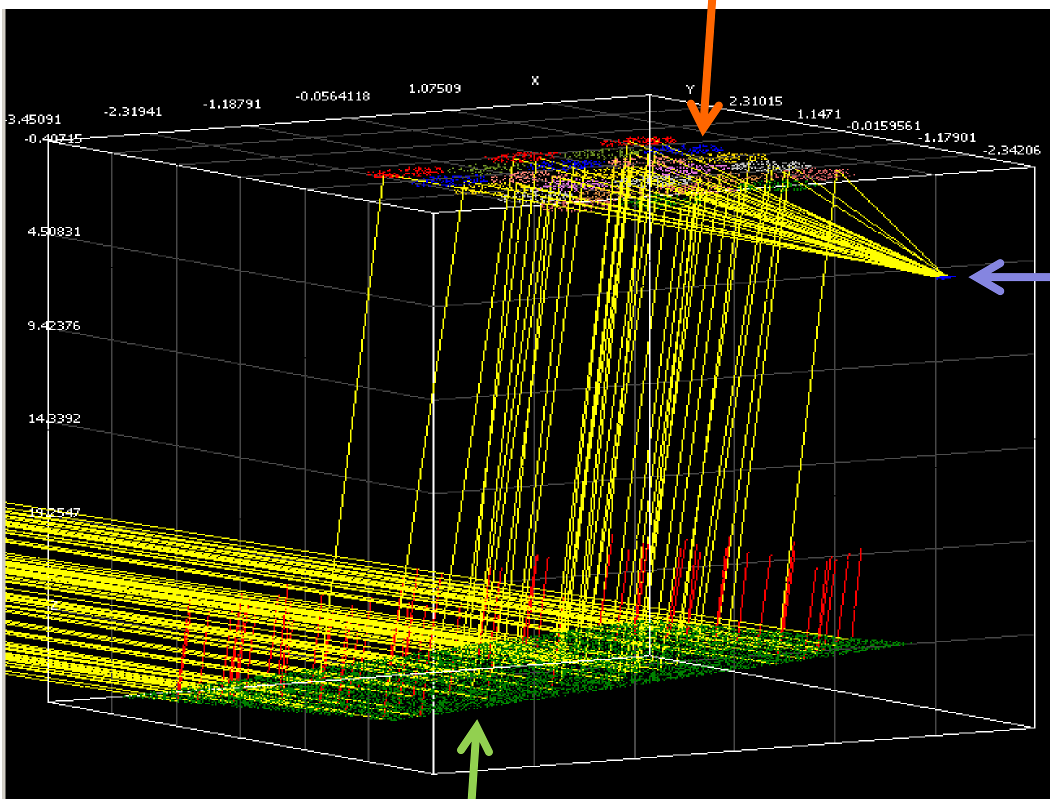
Concentrating Solar Tower

Multi-spectral Solar Cells



Intersection Plot for Concentrator Field

Primary Concentrator Mirror
(25 hexagonal elements each with spherical curvature)

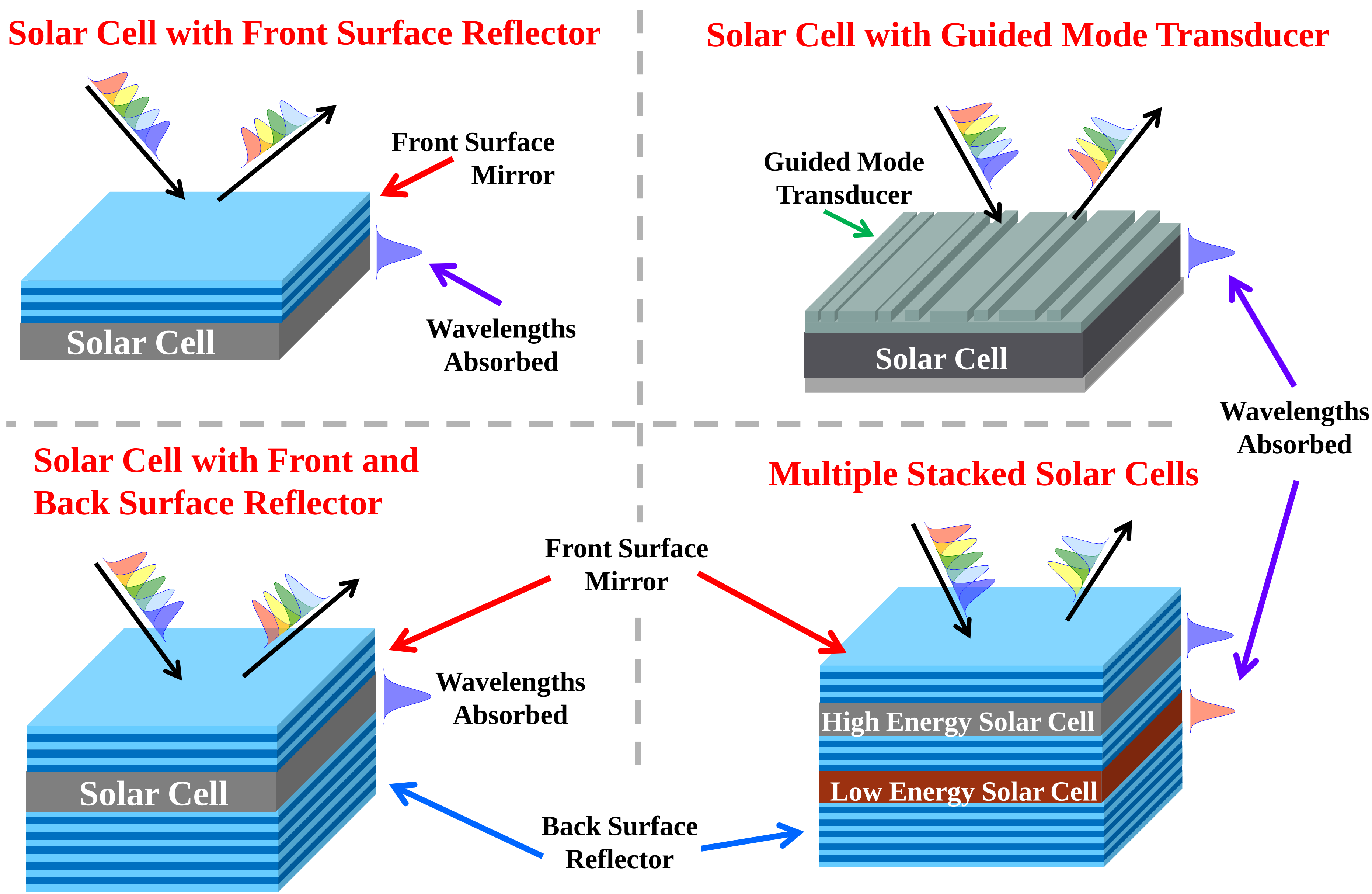


Target Solar
Cell

Incident
Sunlight

Heliostat
(W = 6.2 m, H = 6.83 m)

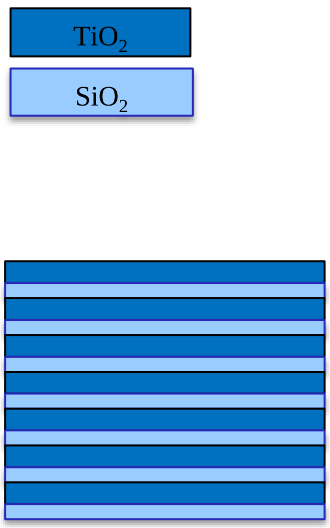
Multi-spectral Solar Cells

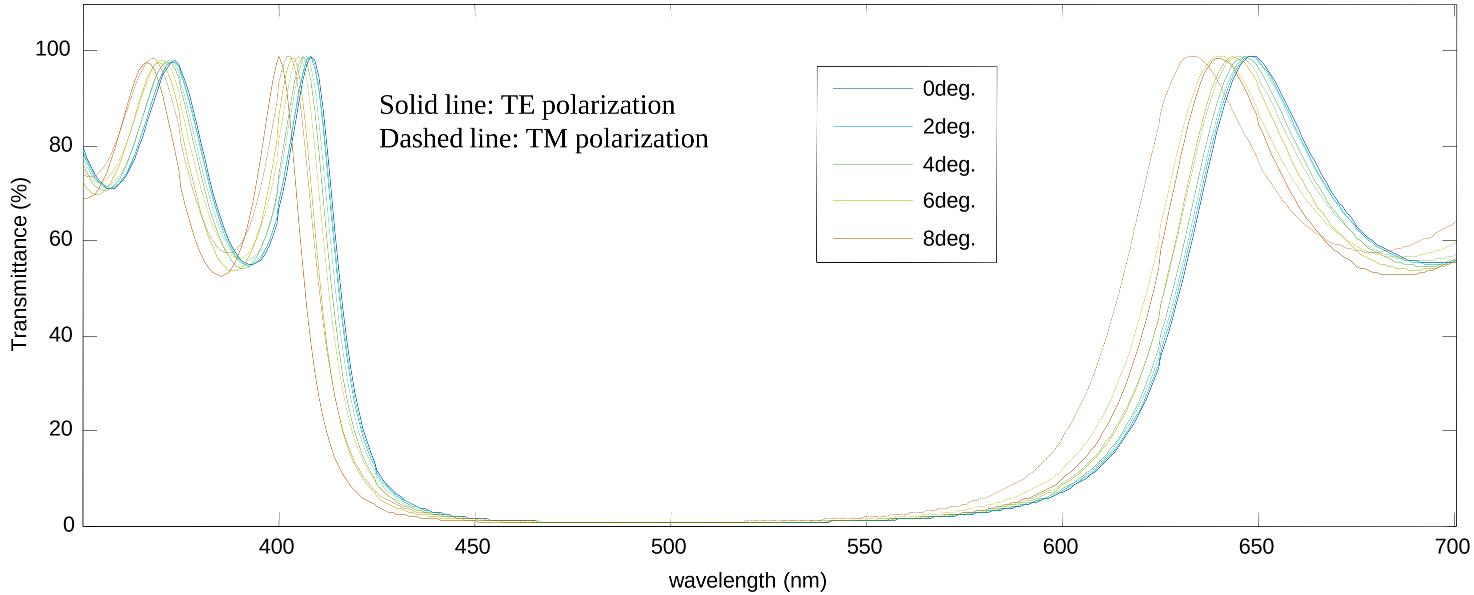


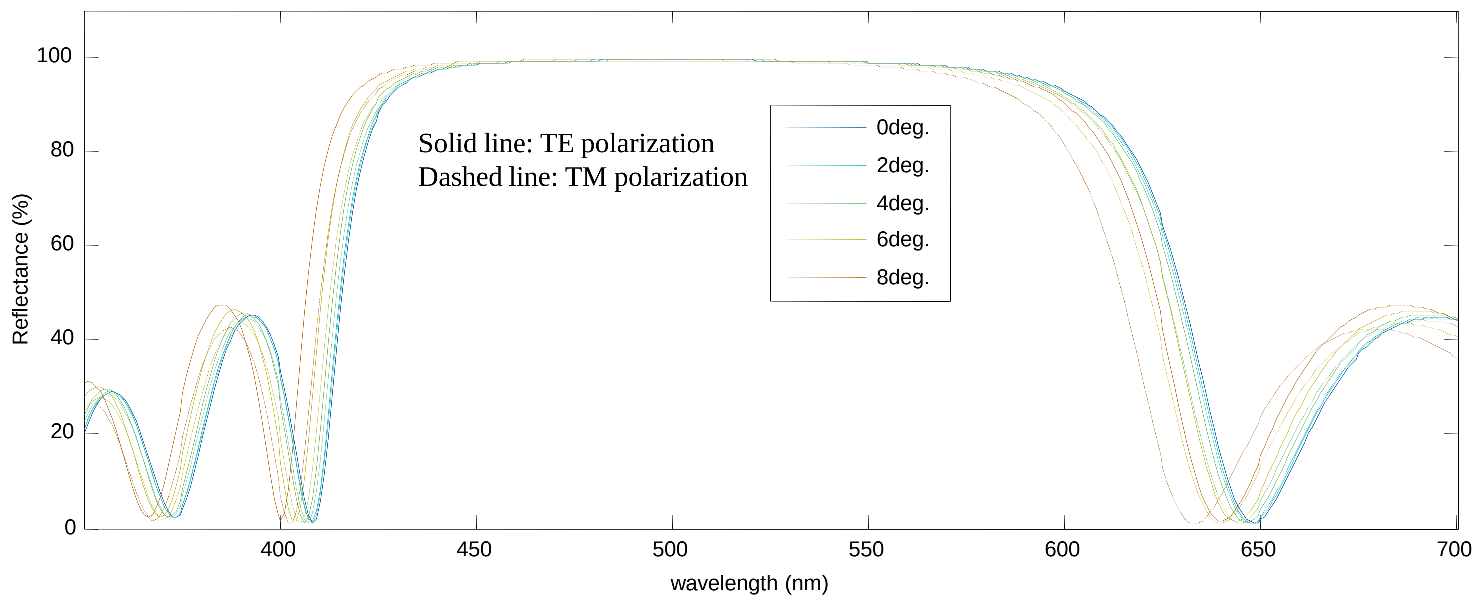
Broadband Photonic Bandgap Reflectors

1D photonic bandgap materials

Center wavelength: 500nm
Bandwidth: 420 - 600nm
7 periods
Index contrast: ~ 2.5/1.46



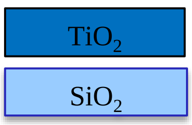


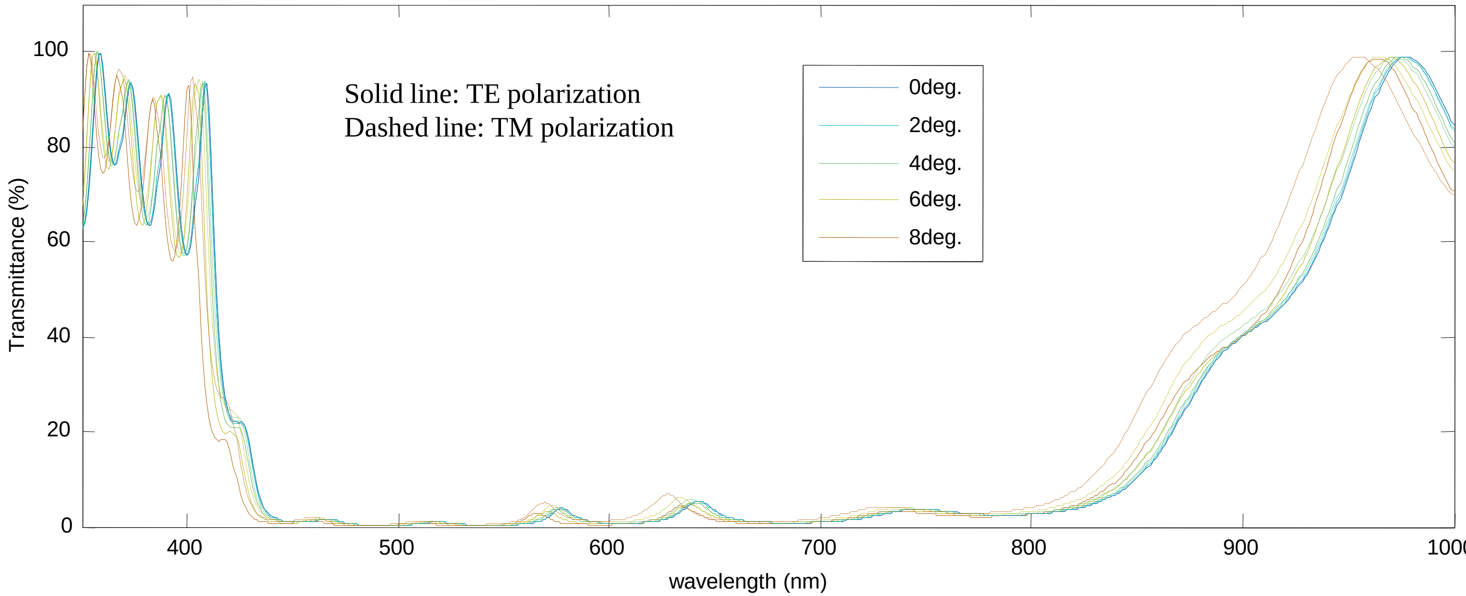


Broadband Photonic Bandgap Reflectors

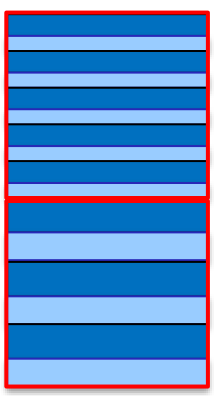
1D photonic
bandgap materials

Center wavelength: 500nm
Bandwidth: 420:600nm
6/6 periods
Index contrast: ~2.5/1.46

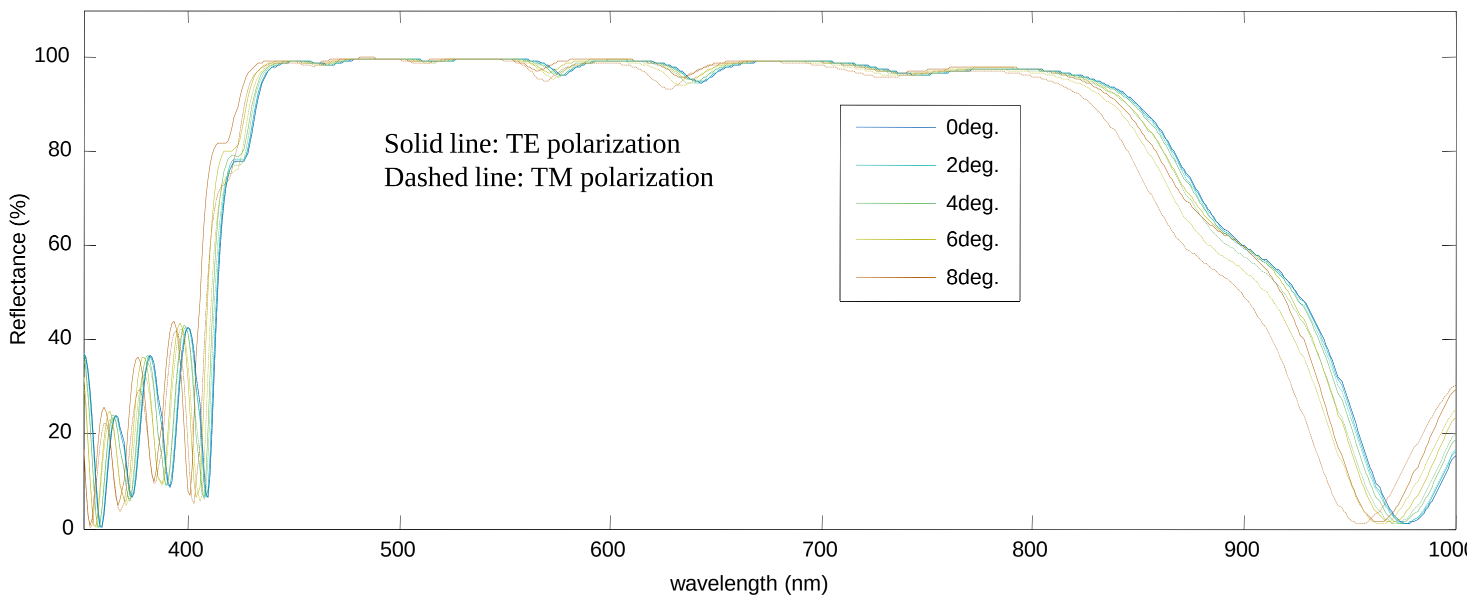




Bandgap #1:
420 – 600 nm

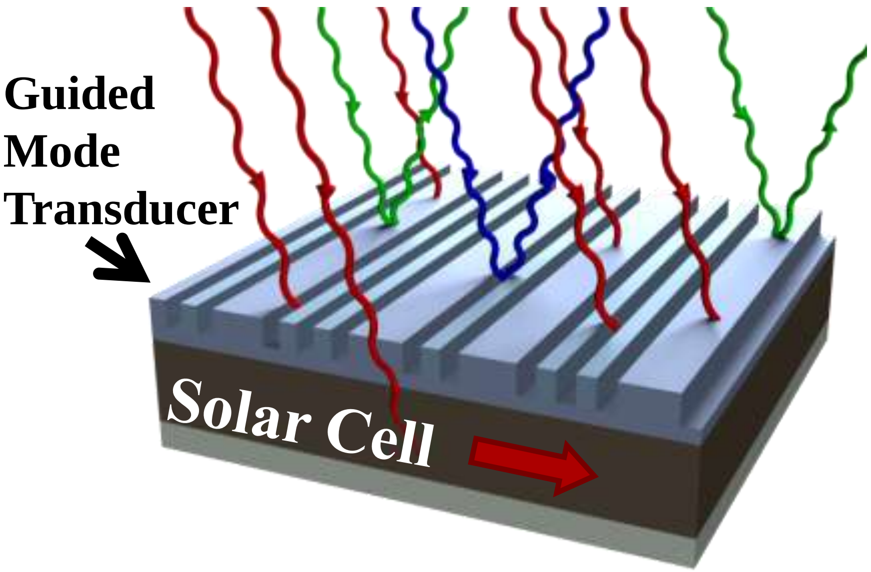


Bandgap #2:
600 – 900 nm

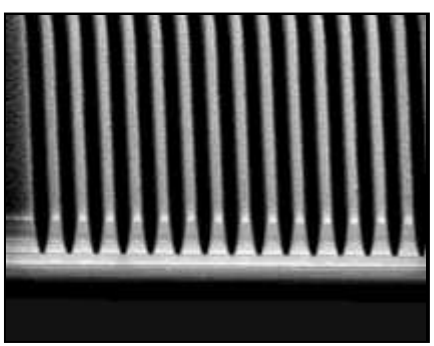


Mode Transducer Enhanced Solar Cells

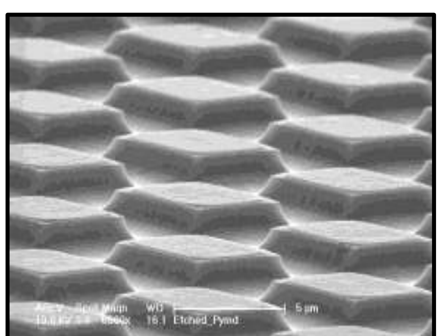
Solar Cell With Guided Mode Transducer



Fabrication of Guided Mode Transducer

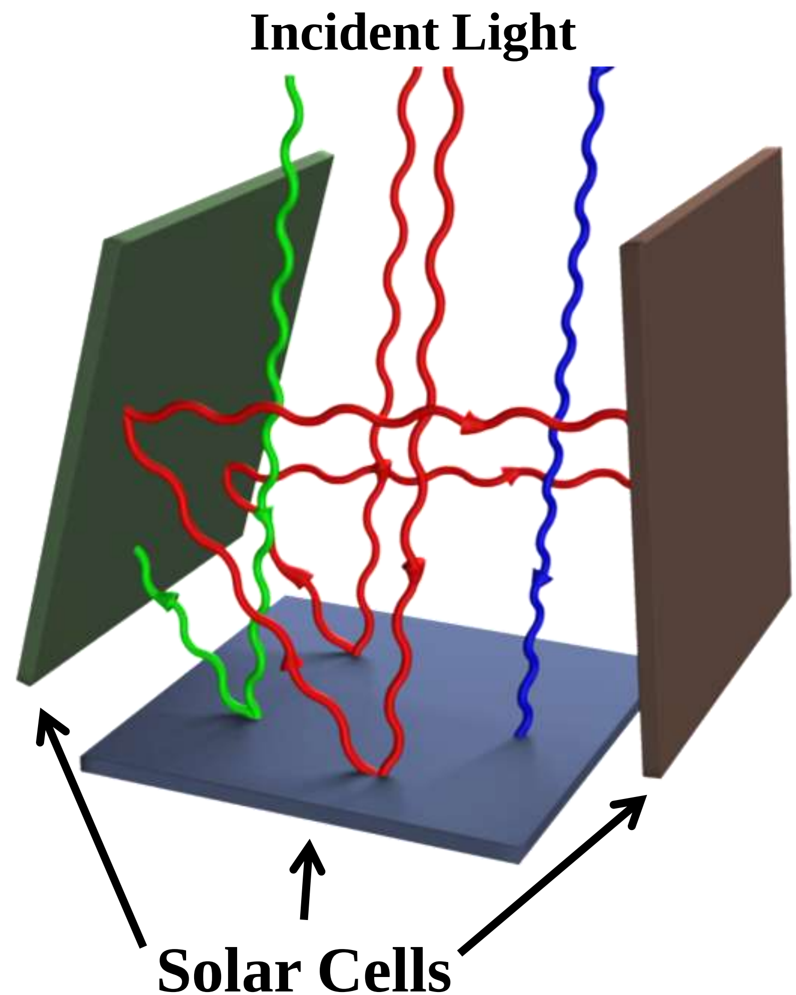


Nano-scale Gratings

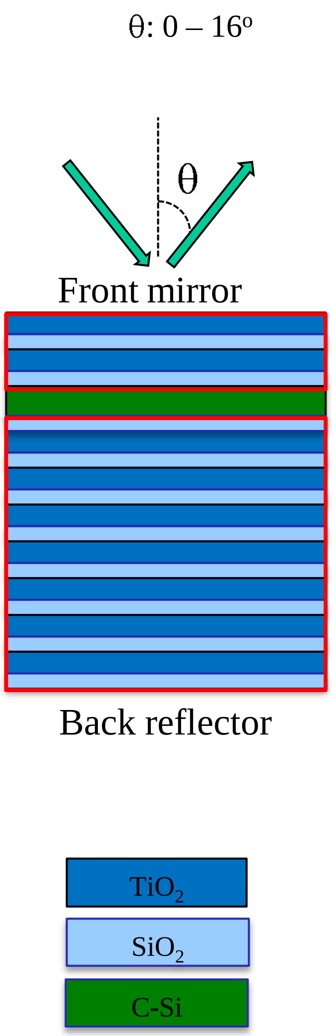


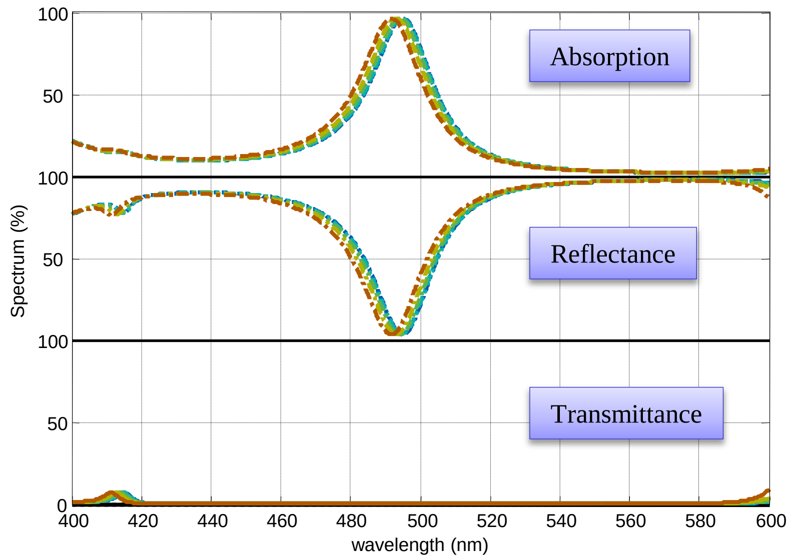
Micro-scale Features

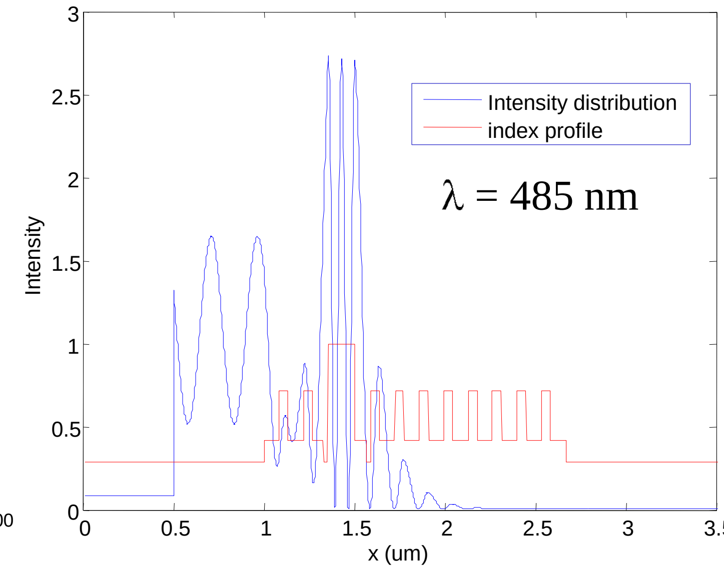
Multiple Guided Mode Transducer Enhanced Solar Cells

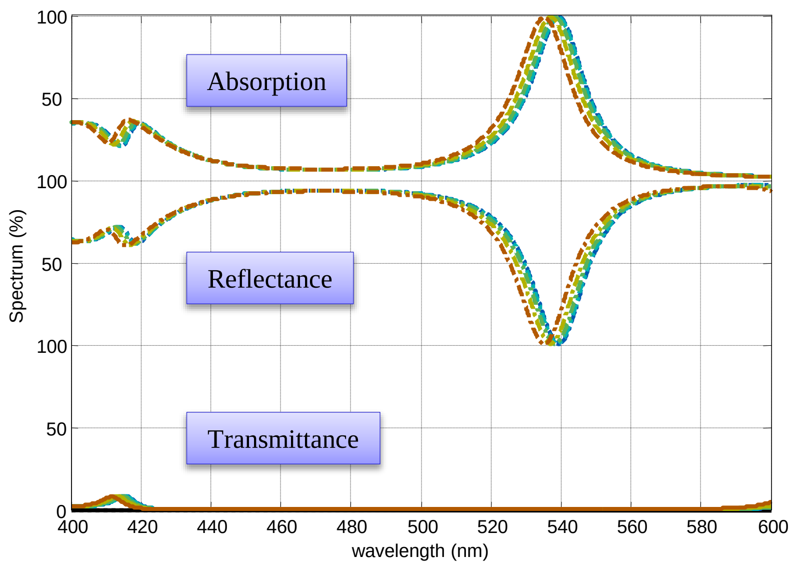


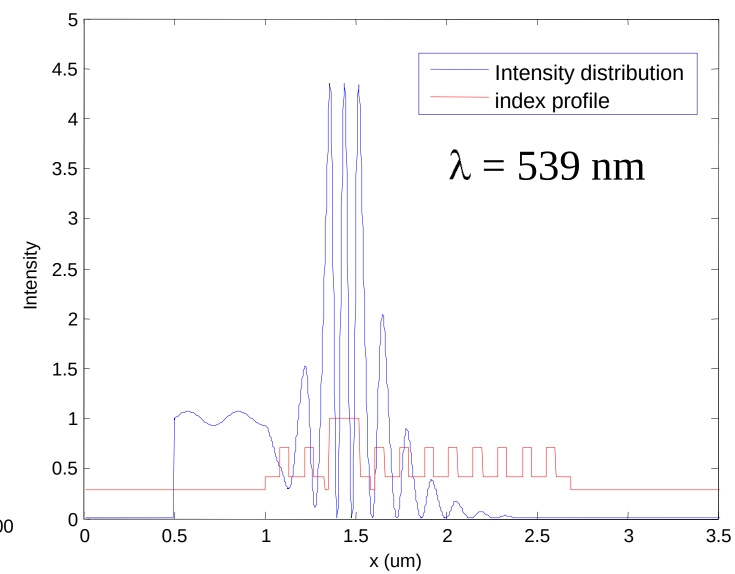
Multi-spectral Solar Cells





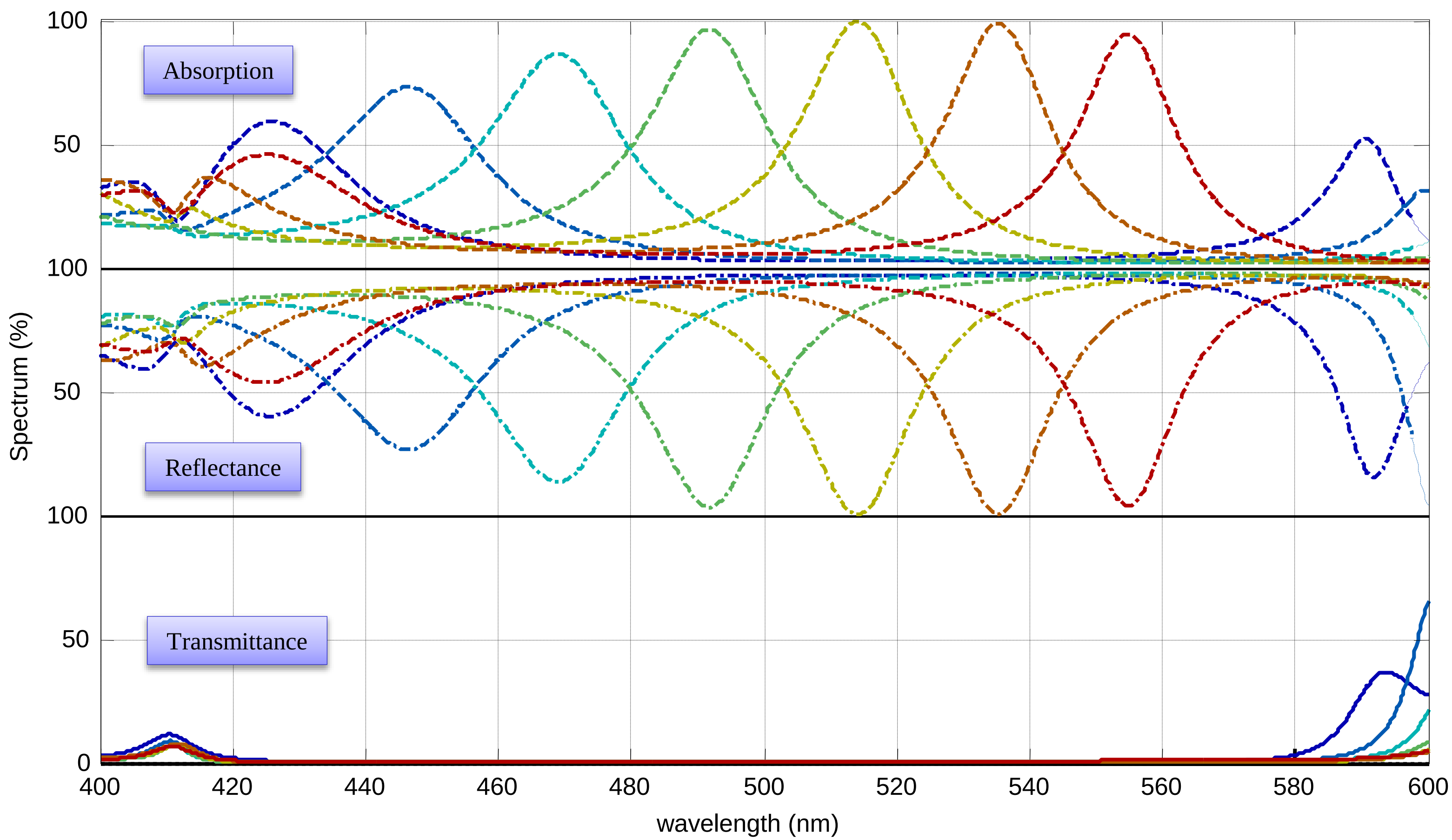






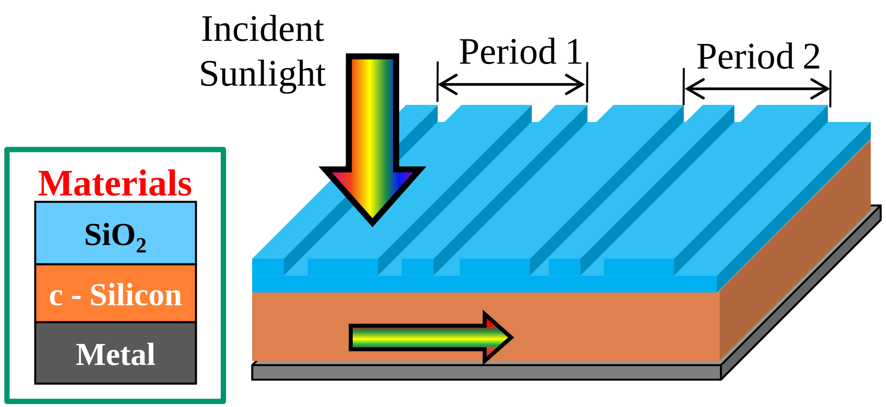
Multi-spectral Solar Cells

- Simply change the active layer (solar cell) thickness, we can tune the peak absorption spectrum
- Further optimization can be used to improve the absorption at the design wavelength

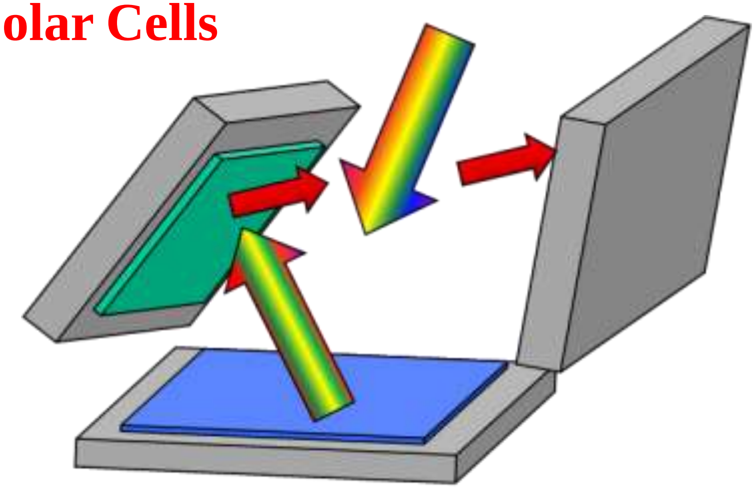


GMRF Enhanced Solar Cells

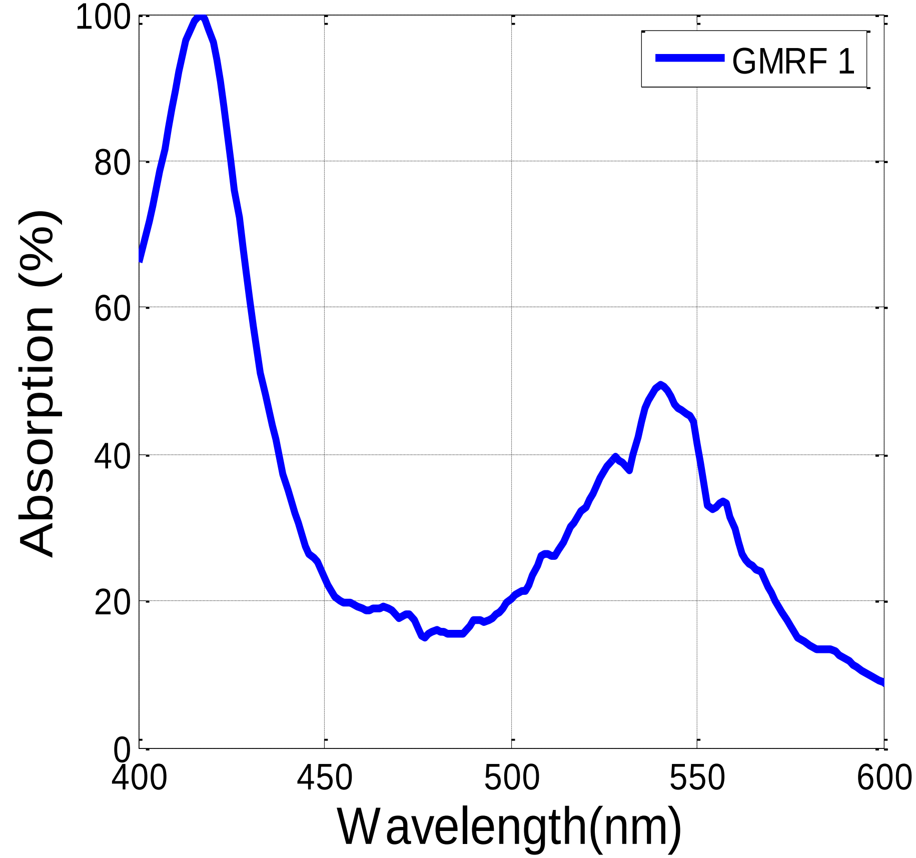
Solar Cell With GMRF



Multiple GMRF Enhanced Solar Cells



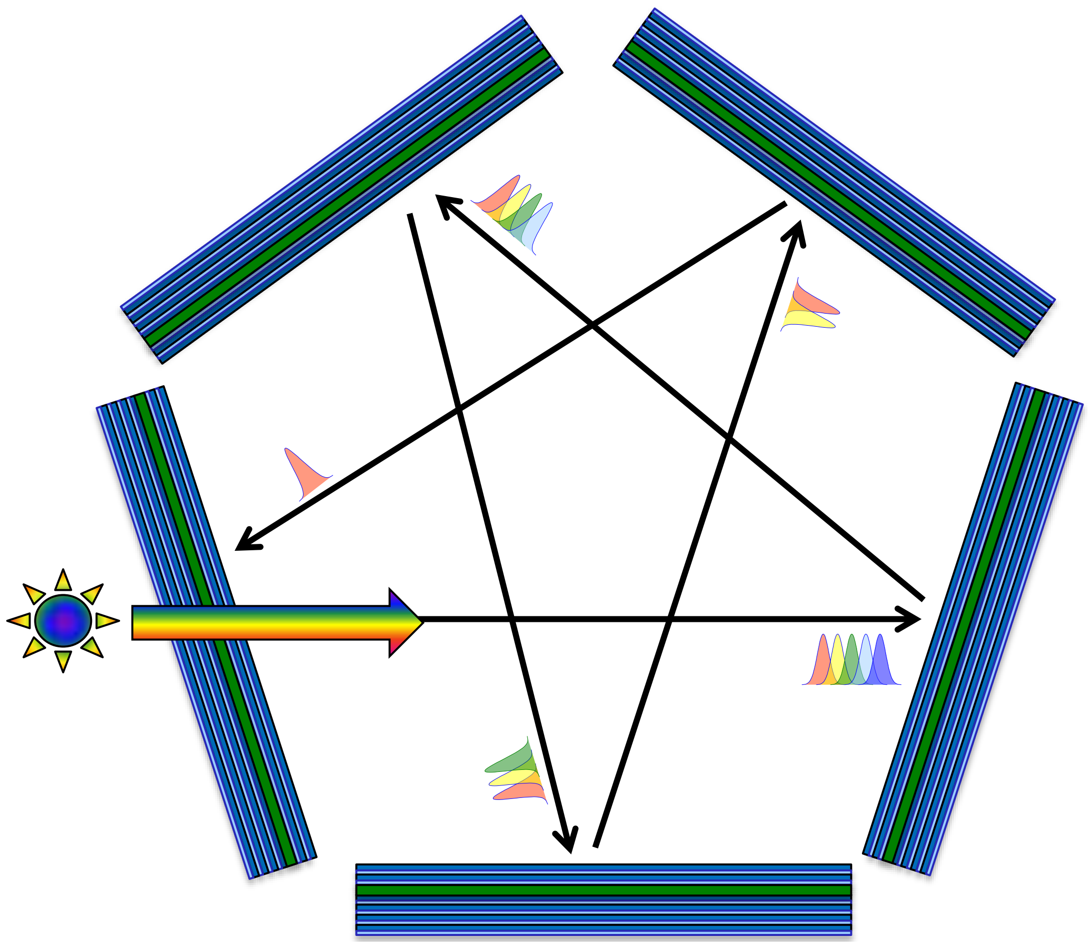
Absorption of Single GMRF Enhanced Silicon Solar Cell



(all less than 1 micron thick)

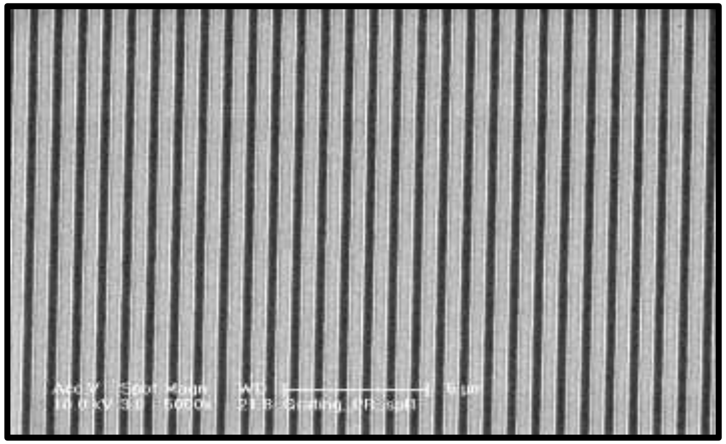
Multi-spectral Solar Cells

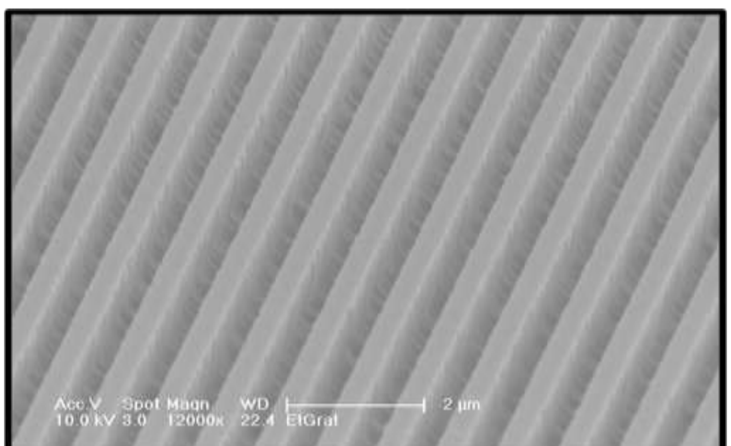
- One-dimensional micro-cavity is designed to capture a narrow band of the solar spectrum.
- Each cavity consists of an ultra wide band back reflector, a front reflector, and an active solar cell material.
- Strong resonances in the active solar cell materials allow the captured photons to have much longer life times, or increased optical path lengths, thereby enabling efficient light trapping.
- Multiple solar cells are arranged along the contour of a cylindrical surface. After the desired wavelength is absorbed in a particular cell, the remainder of the solar spectrum will propagate along the designed optical path and hence, will get absorbed in subsequent cells on the cylindrical surface.



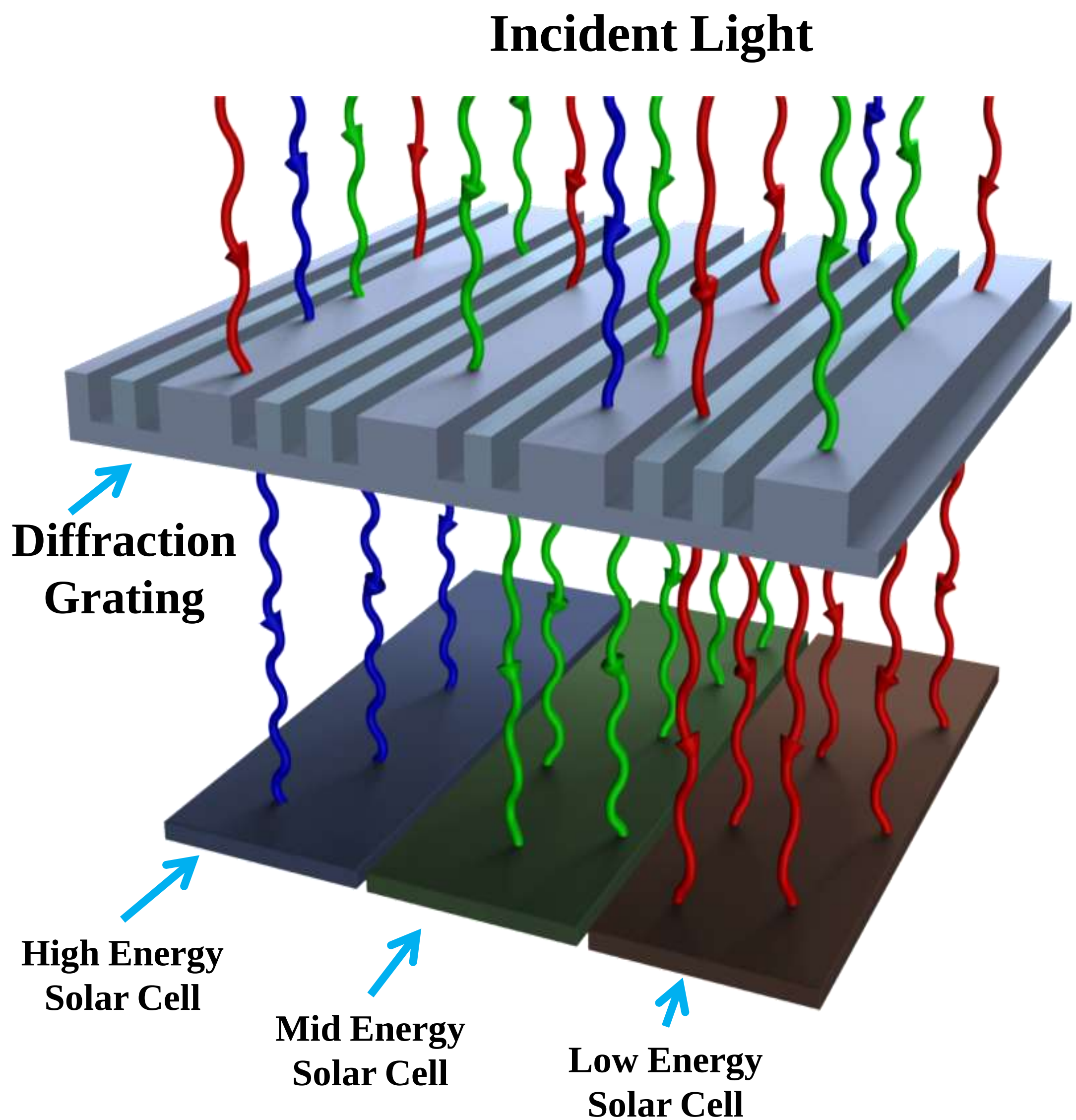
Spectrum Splitting using Gratings

Diffraction Gratings for Light Splitting

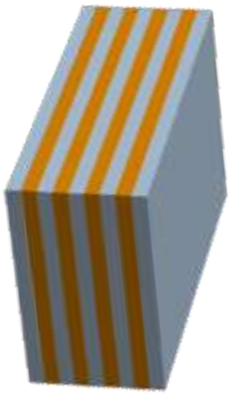


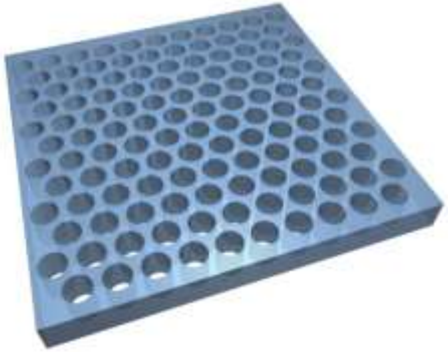


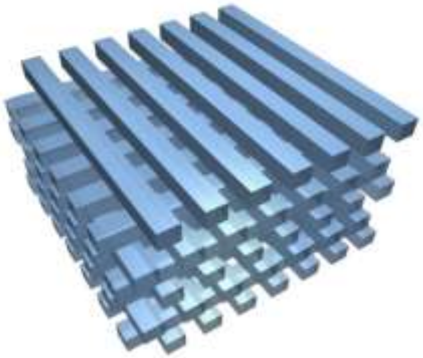
Spectrum Splitting Structures



Photonic Crystals







1D Photonic Crystal 2D Photonic Crystal 3D Photonic Crystal

- A PhC is a periodic arrangement of dielectric or metallic materials with a lattice constant comparable to the wavelength of an electromagnetic wave.

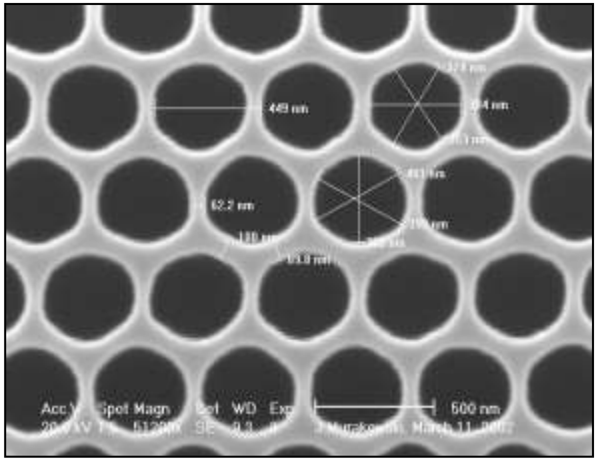
- They were first proposed in 1972 by Vladimir P. Bykov and later in 1987 by Eli Yablonovitch, as a means to control spontaneous emission.

- When a coherent source interacts with a periodic structure, interesting effects occur.

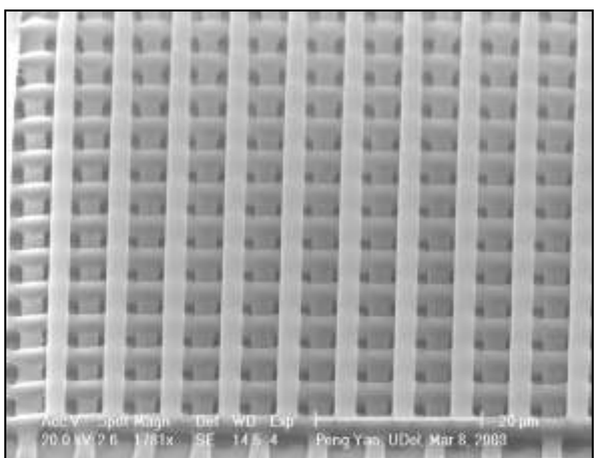
- One of the more interesting effect is the grouping of allowed states into discrete bands, which are separated by ‘band gaps,’ wherein no states are allowed.

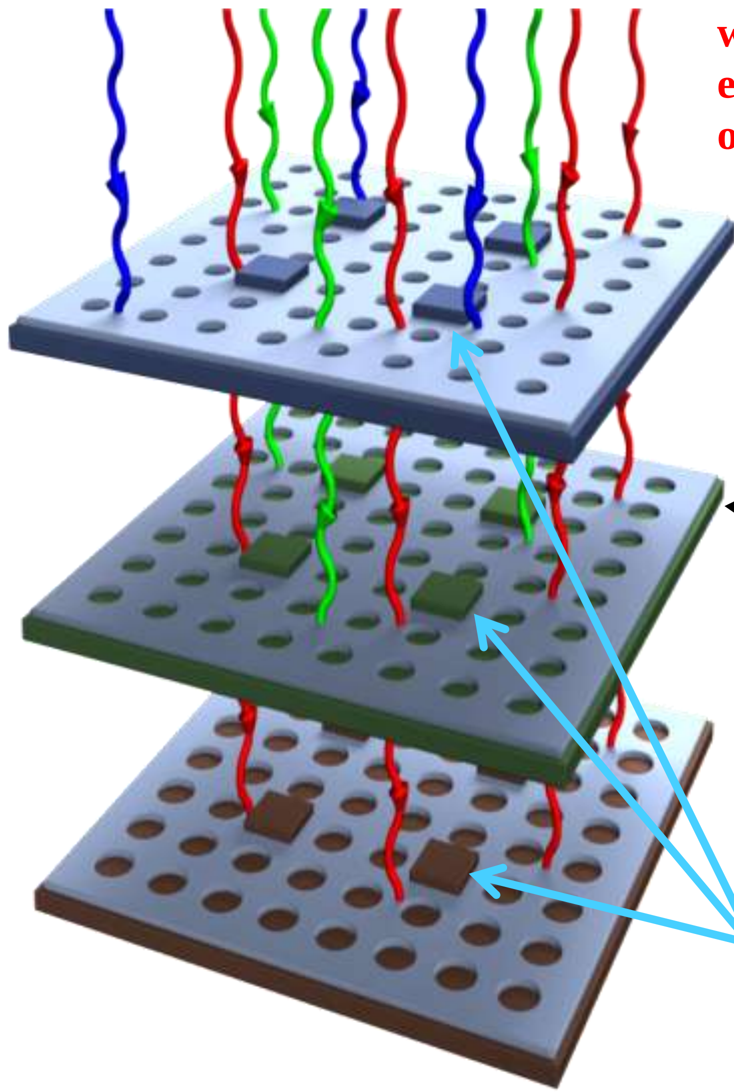
Spectrum Splitting using Photonic Crystals

2D PhC



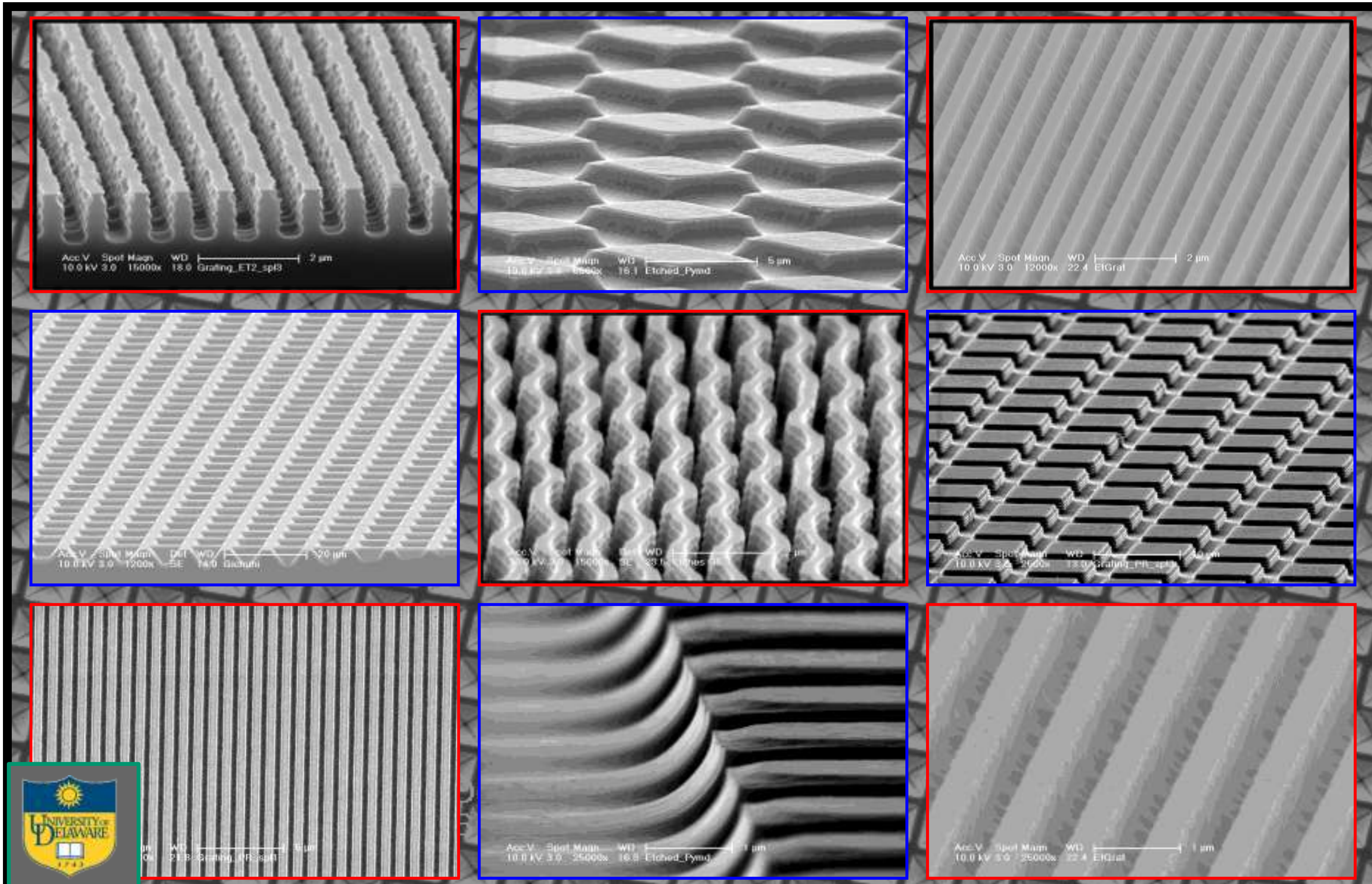
3D PhC





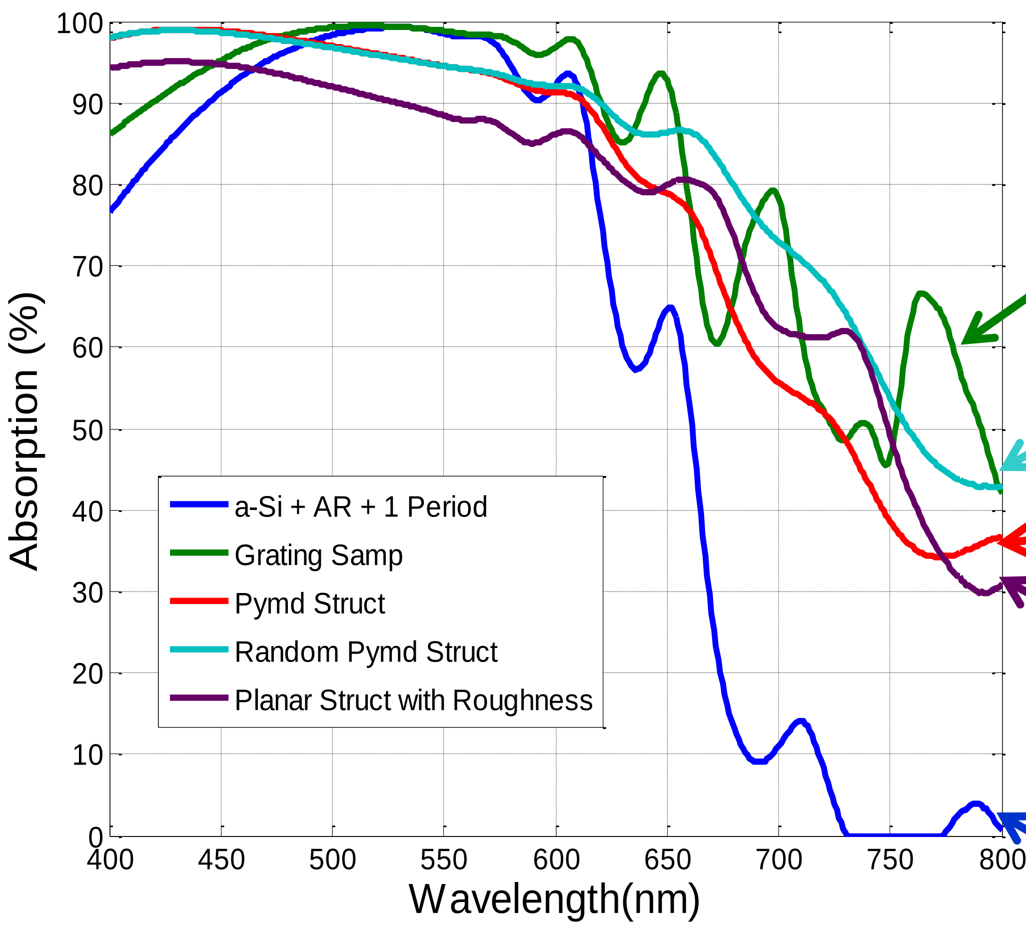
Photonic Crystals filter light of different wavelengths as well as enhance the absorption of the solar cells

Fabrication of Micro and Nano Structures



a-Si Solar Cells on Textured Substrates

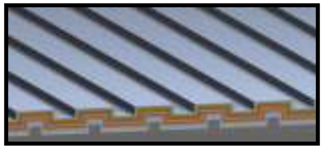
Light Trapping (Measured Absorption)



Materials

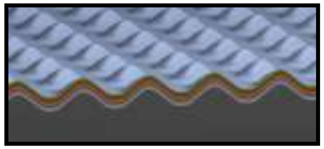
Si_3N_4	SiO_2	a-Si	Al	c-Si

Structures: Absorption (%)

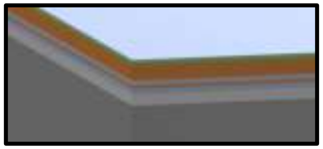


Grating Structure: 83%

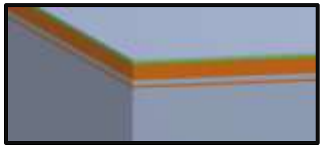
Random Pyramid: 83%



Pyramid Structure: 78%



Planar Structure: 79%



a-Si with AR: 60%